### PART I. INTRODUCTION AND HISTORY

CHAPTER 1. INTRODUCTION	1
Need for Sewerage and Drainage Survey Growth of Population Raw Sewage Discharges Raw Sewage Overflows Lake Washington Pollution Duwamish River Pollution Suburban Sewerage Problems Combined Sewer Problems Metropolitan Aspects of Sewerage and Drainage Objectives and Scope of Survey Objectives of Survey Scope of Survey Scope of Survey and Report Field and Laboratory Work Office Work Information and Data Available to Survey Progress Reports.	1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 3 3 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
CHAPTER 2. HISTORY OF SEWERAGE PROBLEM	6
The Williams Report	.0 .1 .2 .2 .3
CHAPTER 3. PHYSICAL GEOGRAPHY	7
Location and Limits of the Metropolitan Seattle Area	
Topography	

Principal Topographic Features	21
Major Watersheds	21
Principal Hydrographic Features	
Geology	24
Geological History	
Available Geological Information	25
Soil and Foundation Conditions	25
Upland Areas and Hills	25
Lowland Valleys	26
Lake Washington Trough	26
Puget Sound Trough	26
Slide Areas	26
Bedrock	30
Reclaimed Areas	30
Limitation on Local Sewage Disposal	30
Seismic Conditions	31
Climate	31
General Climatic Conditions	32
Temperature	33
Relative Humidity	
Wind	35
Evaporation	36
Occurrence of Sunshine, Clouds and Fog	
Snowfall	
Precipitation	
Types of Storms	
Frequency, Duration and Amount of Rainfall	
Analysis for Storm Drainage Design	
Analysis for Intercepting Sewer Design	
CHAPTER 4. ECONOMIC DEVELOPMENT	45
Land and Water Use	
Residential Development	
Industrial Development	
Industrial Areas	
Industrial Classifications	
Transportation	
Water Transport	
Highway Facilities	
Railroads	
Air Transportation	
Agriculture	
Farm Products	
Fisheries	53

Recreation	
Recreational Facilities	
Boating	54
Local Parks and Beaches	54
Military Installations	
Army	
Navy	
Coast Guard	55
Air Force	55
Trade and Commerce	
Wholesale Trade	55
Retail Trade	56
Foreign Commerce	56
Domestic Commerce	57
Tourist Trade	<b>5</b> 8
Public Utilities	58
Water	59
Sources of Supply	59
Water Quality	62
Annual Water Consumption	62
Winter Water Consumption	63
Industrial Water Consumption	65
Cost of Water	65
Power	<b>65</b>
Power Sources	65
Power Consumption	66
Cost of Power	67
Natural Gas	67
Future Land Use	67
Residential and Local Commercial Areas	70
Industrial and Commercial Areas	70
Employment and Manufacturing	70
Areal Extent of Industrial Zones	
Location of Industrial Acres	73
CHAPTER 5, POPULATION	74
Factors Affecting Population Growth	74
General Population Trends	74
Birth and Death Rate Trends	
Migratory Trends	78
Industrial and Commercial Opportunities	
Utilities and Transportation	
Physical and Social Environment	
Population Projection	
•	82

Population Studies and Projections Available to the Survey Procedure Employed in Population Projection.  Projection of State, Region, and County Populations.  High Population Projection.  Low Population Projection.  Population Projection Within the Study Area  Detailed Distribution of Study Area Population.	. 84 . 84 . 86
PART III. EXISTING SEWERAGE, SEWAGE DISPOSAL AND DRAINAGE	
CHAPTER 6. EXISTING SEWERAGE AND DRAINAGE FACILITIES	. 93
Sewerage Facilities Outside Seattle  Bellevue Sewer District  Bryn Mawr-Lake Ridge Sewer District  East Mercer Sewer District  Lake Hills Sewer District  Mercer Island Sewer District  Roxbury Heights Sewer District  Southwest Suburban Sewer District  Val-Vue Sewer District.  Sewerage and Drainage Improvement District No. 3  Sewerage and Drainage District No. 4  City of Auburn.  City of Issaquah	. 93 . 98 . 101 103 103 103 103 112 113
City of Kent. City of Kirkland City of Renton Private and Semi-Private Systems Boeing-Renton. Boeing Shopping Center. The Highlands Lake Burien Heights Sand Point Naval Air Station Sand Point Homes. Shorewood Apartments Seattle-Tacoma Airport Operation and Maintenance	114 115 115 120 120 120 120 120 122
Storm Drainage Facilities Outside Seattle	122
Sewerage and Drainage Facilities of the City of Seattle	123 123 123

Overloaded Sewers	
CHAPTER 7. SEWAGE CHARACTERISTICS	149
Nature and Scope of Sewage Studies	149
Sewage Volume	
Sewage Strength and Composition	
Infiltration	
Industrial Waste	
Sewage Volume and Composition	
City of Seattle	
Lake City System	
Greenwood System	
Diagonal Avenue System	
North Trunk System	
Ballard System	
Rainier Avenue System	
City of Auburn	
Bellevue Sewer District	
Bryn Mawr-Lake Ridge Sewer District	
City of Kent	
City of Kirkland	
City of Renton	
Shorewood Apartments	
Southwest Suburban Sewer District	
Relative Freshness of Metropolitan Area Sewage	
Presence of Grit in Combined Sewage	
Infiltration and Storm Inflow	
Lake City System	
Scope of Infiltration Study	166
Results of Infiltration Measurements	
Infiltration and Storm Inflow in Other Separate Systems	174
Combined Systems	175
Characteristics of Industrial Waste	176
Sources and Volume of Industrial Waste	176
Strength and Composition of Industrial Waste	
Summary of Sewage Characteristics	
Volume of Sanitary Sewage	
Volume of Industrial Waste	
Infiltration and Storm Inflow	
Infiltration	
Storm Inflow to Sanitary Sewers	
Composition	

CHAPTER 8. ENVIRONMENTAL AND ECONOMIC EFFECTS	
OF SEWERAGE AND DRAINAGE DEFICIENCIES	181
Community Sewerage Systems	181
Overloading of Seattle Sewers	
Deficiencies in Other Systems	
Individual Sewage Disposal Systems	
Basis for Need of Public Sewerage	
Extent of Area in Need of Public Sewerage	
Sewage Disposal in Unsewered Areas	
Effect of Unfavorable Soil Conditions	
Effect of Crowded Installations	
Cost of Sewage Disposal in Unsewered Areas	
Removal of Sewage from Inland Areas	
Conditions in Environmental Waters	
Bacterial Contamination	
Summary of Bacteriological Studies, 1942-1951	
Seattle-King County Health Department Bacteriological Study, 1952-56	
Nuisance Conditions	
Chemical and Biological Effects	
Effects of Inadequate Drainage	200
PART IV. BASIS FOR SEWERAGE AND DRAINAGE PLANNING CHAPTER 9. PRINCIPLES AND FUNCTIONS OF SEWERAGE AND	
DRAINAGE	
Purposes of Sewerage	203
Public Health Aspect of Sewerage	
Water Pollution Aspects of Sewerage	203
Development of Water Pollution Problems	203
Significance of Water Pollution	
Control of Water Pollution in Washington	
Approval and Permit Procedures	
Determination of Water Uses	
Quality Requirements	
Sewerage Functions and Methods	
Separate versus Combined Collection Systems	
Methods of Sewage Treatment and Disposal	
Preliminary Treatment	
Grit Separation	
Sedimentation	
Biologic Oxidation	
Sludge Digestion	
Disposal of Digested Sludge	213
Disinfection	

Effluent Disposal	214
By-Product Recovery and Utilization	
Water	
Gas	
Digested Sludge	214
Agencies for Providing Sewerage Service	
Metropolitan Sewerage Agencies	
Sewerage Agencies in Washington	
	1
CHAPTER 10. SEWAGE DISPOSAL IN LAKE WASHINGTON	
Water Uses and Water Quality Requirements	219
Water Uses	
Lake Washington and Tributary Waters	219
Lake Union - Ship Canal	222
Water Quality Requirements	222
Bacteriological Requirements	222
Esthetic Requirements	224
Protection of Fish Life	224
Prevention of Algal Growths	224
Pollution Control Commission Policy Relating to	
Sewage Discharges to Lake Washington	224
Capacity of Lake Washington and Tributary Waters to Receive Sewage	
Nutrient Balance	225
Previous Studies	225
Field Studies	226
Nutrient Inflow	226
Nutrient Outflow	232
Nutrient Storage and Reuse	234
Future Nutritional Loads	236
Biological Response	237
Lake Washington's Behavior	238
Comparative Studies of Other Lakes	240
Phosphorus Limits for Lake Washington	242
Requirements for Disposal of Sewage in the Lake Washington Drainage Basin	244
Prevention of Nuisance Conditions	244
Prevention of Bacteriological Contamination	245
CHAPTER 11. SEWAGE DISPOSAL IN PUGET SOUND	248
Conditions Affecting Sewage Disposal	248
Beneficial Uses of Water	
Recreational Use	
Fishing and Fisheries.	
TENHING CHU L'ICHCLIOD	4±3

Navigation	$^{249}$
Industrial and Commercial Uses	249
Probable Water Quality Criteria	249
Characteristics of Puget Sound	250
Temperature and Chemical Characteristics	251
Density	251
Tides and Currents	251
Wind Induced Currents	251
Mechanics of Effluent Discharge	253
Initial Dilution	254
Subsequent Dilution	255
Reduction of Coliform Organisms	255
Mechanics of Digested Sludge Disposal	255
Deposition and Dilution	256
Diffusion	257
Resuspension	257
Biological Effects	257
Disposal in Puget Sound	259
Nature and Scope of Current Studies	261
Current Study Procedure	262
Interpretation of Current Study Results	264
Point Wells to Meadow Point	265
West Point	265
Elliott Bay	266
Alki Point	
Salmon Creek	268
Point Pulley	269
Des Moines	271
nalysis of Possible Disposal Sites	271
Methods of Analysis	271
Richmond Beach	
Boeing Creek	274
Piper Creek	274
South of Piper Creek	275
West Point	275
Elliott Bay	276
Alki Point	
Southwest Suburban	277
Seahurst	
Miller Creek	
Des Moines	
Redondo Beach	

CHAPTER 12. SEWAGE DISPOSAL IN GREEN-DUWAMISH RIVER	281
Physical Characteristics of Green-Duwamish River	281
Water Uses and Water Quality Requirements	
Water Uses	281
Water Quality Requirements	
Effects of Present Wastes Discharges	
Capacity of Green-Duwamish River to Receive Sewage	
Green River	
Oxygen Resources	
Oxygen Balance	286
Duwamish Estuary	
Mixing and Diffusion	288
Flushing Time	289
Oxygen Resources	290
Oxygen Balance	291
Maximum Permissible BOD Loadings	293
CHAPTER 13. DESIGN CRITERIA AND BASIS OF COST ESTIMATES	295
Preliminary Layouts	
Design Period	295
Use of Existing Facilities	295
Design Criteria	295
Design Loadings - Separate Sanitary Systems	
Design Loadings - Storm Drainage Systems	
Coefficient of Runoff	297
Rainfall Intensity and Frequency	
Time of Concentration	
Design Loadings - Combined Systems	
Design Loadings - Intercepting Sewers	
Trunk and Intercepting Sewers	
Storm Drains	
Storm Channels	
Combined Sewers	
Inverted Siphons and Force Mains	
Bypass Structures	
Storm Water Pumping Stations	
Sewage Pumping Stations	
Sewage Treatment Plants	
Construction Costs	
Trunk Sewers and Storm Drains	
Force Mains and Inverted Siphons	
Intercepting Sewers	307
Tunnels	308

Submarine Outfalls	. 309
Storm Water Pumping Stations	
Sewage Pumping Stations	
Sewage Treatment Plants	
Separation Costs	
Engineering and Contingencies	
Annual Costs	
Interest and Depreciation	
Operation and Maintenance	
Trunk and Intercepting Sewers	
Sewage Treatment Plants	
Sewage Pumping Stations.	
Softing a marking management, the contract of	
CHAPTER 14. SEWERAGE AND DRAINAGE SUBAREAS	. 314
Sewerage Service Areas	
North Lake Sammamish Sewerage Area	
South Lake Sammamish Sewerage Area	
East Lake Washington Sewerage Area	
North Lake Washington Sewerage Area	
Northwest Lake Washington Sewerage Area	
South Lake Washington Sewerage Area	
Green River Sewerage Area	
Southwest Lake Washington Sewerage Area	
Elliott Bay Sewerage Area	. 332
Lake Union Sewerage Area	
South Puget Sound Sewerage Area	
Redondo Beach Subarea	. 336
Des Moines Subarea	. 337
Miller Creek Subarea	. 337
Southwest Suburban Subarea	. 338
West Seattle Subarea	. 339
North Puget Sound Sewerage Area	. 339
Seaview Subarea	. 339
Piper Creek Subarea	. 340
Boeing Creek Subarea	. 340
Drainage Areas	. 340
PART V. SEWERAGE AND DRAINAGE PLANS	
CHAPTER 15. DEVELOPMENT OF SEWERAGE PLANS	. 342
Method of Analysis	. 342
Central Sewerage Projects	
Sanarata Draigets for Independent Sawarara Areas	3/19

Possible Treatment Plant and Disposal Sites	343
Disposal Sites	343
Puget Sound	343
Green-Duwamish River	343
Treatment plant Sites	343
Core Plan Sites	343
Sites for Plants for Separate Sewerage Areas	344
Preliminary Design of Sewerage Facilities:	344
Core Plan Service Area	344
Sewage Flows	344
Use of Existing Facilities	345
Interception of Combined Sewers	345
Overflow Frequencies	345
Interceptor Capacity	346
Combined Interceptor	346
Separation	346
Holding Tanks	346
Analysis of Interception Methods	347
Description of Core Plans	347
Core Plan A	
Intercepting Sewers	
Sewage Treatment Plant	
Effluent Disposal	
Construction Cost	
Core Plan B	354
Intercepting Sewers - Renton System	
Sewage Treatment Plant - Renton System	
Effluent Disposal - Renton System	
Intercepting Sewer - West Point System	
Sewage Treatment Plant - West Point System	
Effluent Disposal - West Point System	
Construction Cost	
Core Plan C	
Intercepting Sewers - Elliott Bay System	
Sewage Treatment Plant - Elliott Bay System	
Effluent Disposal - Elliott Bay System	
Intercepting Sewers - West Point System	
Sewage Treatment Plant - West Point System	362
Effluent Disposal - West Point System	
Construction Cost	
Core Plan D	
Renton System	
Intercepting Sewers - Elliott Bay System	
Sewage Treatment Plant - Elliott Bay System	

Effluent Disposal - Elliott Bay System	
West Point System	
Construction Cost	
Comparison of Core Plans	
Construction Costs	367
Annual Costs	367
Factors Other Than Cost	<b>36</b> 8
Duplication of Operation	368
Interference with Business Activity	
Quality of Effluent	369
Expansion of Treatment Facilities	369
Simplicity of Treatment Processes	369
Esthetic Considerations	
Selection of Most Acceptable Core Plan	369
Feeder Sewers for Core Plan B	372
Renton System	372
West Point System	372
Possible Modifications of Core Plan B	372
Modification of East Side Sewer	372
Alternative 1	376
Alternative 2	376
Alternative 3	376
Construction Costs	377
Modification of Renton Plant	377
Modification of West Point Plant	377
Separate Projects for Individual Sewerage Areas	378
Apportionment of Core Plan B and Feeder Sewer Costs	<b>3</b> 78
Construction Costs	378
Annual Costs	379
North Lake Sammamish, South Lake Sammamish and	
East Lake Washington Sewerage Areas	379
North Lake Sammamish, North Lake Washington and	
Northwest Lake Washington Sewerage Areas	387
Plan I	391
Plan II	391
Plan III	391
Plan IV	392
Plan V	<b>39</b> 5
Comparison of Plans	
Selection of Most Acceptable Plan	395
South Lake Washington and Green River Sewerage Areas	400
Plan I	400
Plan II	401
Comparison of Plans	
Selection of Most Accentable Dlan	402

	Southwest Lake Washington, Elliott Bay and Lake Union Sewerage Areas	
	South Puget Sound Sewerage Area	
	Redondo Beach Subarea	
	Des Moines Subarea	
	Miller Creek Subarea	
	Southwest Suburban Subarea	
	West Seattle Subarea	
	Comparison of Independent Systems with Central Sewerage Project	
	North Puget Sound Sewerage Area	
	Piper Creek Subarea	
	Boeing Creek Subarea	
	Comparison of Independent Systems with Central Sewerage Project	
	ervice Sewers	
	North Lake Sammamish Sewerage Area	
	South Lake Sammamish Sewerage Area	
	East Lake Washington Sewerage Area	
	North Lake Washington Sewerage Area	
	Northwest Lake Washington Sewerage Area	
	South Lake Washington Sewerage Area	
	Green River Sewerage Area	
	Southwest Lake Washington Sewerage Area	
	Elliott Bay Sewerage Area	
	Lake Union Sewerage Area	
	utline of Proposed Sewerage Projects	
	dministration of Proposed Sewerage Facilities	
	Central Control	
	Predesign Investigations	
	Engineering Design and Control of Construction	
	Enforcement of Design Criteria	
	Infiltration and Storm Inflow	
	Industrial Wastes	447
CE	HAPTER 16. STAGE CONSTRUCTION OF SEWERAGE FACILITIES	448
Ва	asis of Construction Program	448
	age I Construction, 1960-1970	
	Renton System Sewers	
	Renton System Treatment Plant	
	Flow Diagram and Design Data	453
	Pretreatment Facilities	
	Influent Pumping	
	Power Generation	
	Preaeration and Grit Removal	
	Primary Sedimentation	
	Aeration	457
		T() (

Secondary Sedimentation	457
Effluent Chlorination	
Raw Sludge Pumping	
Sludge Digestion and Disposal	
Effluent Outfall	
West Point System Sewers	
West Point System Treatment Plant	
Flow Diagram and Design Data	459
Coarse Grit Removal	
Pretreatment Facilities	
Influent Pumping	461
Power Generation	
Preaeration and Grit Removal	
Sedimentation	461
Effluent Chlorination	461
Raw Sludge Handling	461
Sludge Digestion and Disposal	461
Effluent Outfall	462
Independent Systems	462
Des Moines Subarea, South Puget Sound Sewerage Area	462
Miller Creek Subarea, South Puget Sound Sewerage Area	463
Southwest Suburban Subarea, South Puget Sound Sewerage Area	
West Seattle Subarea, South Puget Sound Sewerage Area	
Piper Creek Subarea, North Puget Sound Sewerage Area	
Boeing Creek Subarea, North Puget Sound Sewerage Area	
Temporary Sewage Treatment Plants	
Stage II Construction, 1970—1980	
Renton System Sewers	
Renton System Treatment Plant	
West Point System Sewers	
West Point System Treatment Plant	
Independent Systems	
Stage III Construction	
Summary of Stage Construction Costs	471
CHAPTED 15 DEVELOPMENT OF CHOOM DRADINGS STANS	450
CHAPTER 17. DEVELOPMENT OF STORM DRAINAGE PLANS	472
Use of Natural Watercourses	472
Legal Aspects of Storm Drainage	472
Central Control of Storm Drainage Facilities	
Preliminary Design of Storm Drainage Facilities	
Design Period	
Design Criteria	
Storm Water Conduits	

Storm Drainage for Local Service Areas	474
Use of Street Gutters for Conveying Storm Flows	474
Storm Drain Laterals for Foundation Drains	475
Street Inlets	475
Storm Drainage Plans for Selected Areas	475
Kirkland-Houghton Area	
Mountlake Terrace Area	
Des Moines Area	
Kent Area	
Summary of Drainage Costs	
CHAPTER 18. SEPARATION OF COMBINED SEWERS IN SEATTLE	490
Extent of Separation Requirements	490
Design Criteria	490
Analysis of Existing System	
Previous Studies	
Present Studies	
Type of Separation	
Routes of Storm Drains	
Basis of Cost Estimates	
Separation Requirements in Selected Areas	
Selection of Areas for Study	
District 6 - Briarcliff	
District 17 - Wedgewood	
District 23 - Southwest Seattle	
District 29 - South Magnolia	
District 33 - Madison Park.	
District 58 - East Madison	
Recommended Separation Program	
Summary of Separation Costs	
Construction of New Sanitary Sewers	
Construction of New Storm Drains	
Construction of New Storm Drains	5Z1
CHAPTER 19. FINANCING OF RECOMMENDED FACILITIES	523
Financial Resources of the Metropolitan Area	<b>52</b> 3
Application of Population Forecasts	
Projected Growth of Assessed Valuation	<b>52</b> 3
Projected Increases in Service Connections	
Financing Powers and Limitations of a Metropolitan Agency	
Supplemental Income	
Property Taxes and General Obligation Bonds	
Service Charges and Revenue Bonds	
Special Assessments	
Federal Aid	

Basis for Development of Financing Programs	527
Concepts of Metropolitan Financing	527
Benefits of a Metropolitan Sewerage and Drainage Program	528
Metropolitan Financing by Bond Issues	528
General Obligation Bonds	528
Revenue Bonds	
Special Assessment Bonds	
Reimbursement for Existing Sewerage Facilities	
Policy with Respect to Reimbursement	
Effect of Reimbursement	
Financial Requirements	
Capital Funds	
Operation and Maintenance	
Fiscal and Administrative Costs	
Financing the Sewerage Program	
Revenue Bond Financing	
Five-Year Example	
Ten-Year Example	
Sinking Fund Alternative	
Sewer Service Charge	
General Obligation Bond Financing	
Comparison of Revenue Bond and General Obligation Bond Financing	
Independent Financing of Separate Sewerage Systems	
Financing the Storm Drainage and Separation Programs	
Storm Drainage	
Separation of Combined Sewers	
PART VI. FINDINGS AND RECOMMENDATIONS	
CHAPTER 20. SUMMARY OF FINDINGS	545
Part I. Introduction and History	
Chapter 1. Introduction	
Chapter 2. History of Sewerage Problem	
Part II. Characteristics of Metropolitan Seattle Area	
Chapter 3. Physical Geography	
Chapter 4. Economic Development	
Chapter 5. Population	547
Part III. Existing Sewerage, Sewage Disposal and Drainage	547
Chapter 6. Existing Sewerage and Drainage Facilities	547
Chapter 7. Sewage Characteristics	548
Chapter 8. Environmental and Economic Effects of Sewerage and	
Drainage Deficiencies	
Part IV. Basis for Sewerage and Drainage Planning	
Chapter 9. Principles and Functions of Sewerage and Drainage	549

Chapter 10.	Sewage Disposal in Lake Washington					
Chapter 11.	Sewage Disposal in Puget Sound 551					
Chapter 12.	Sewage Disposal in the Green-Duwamish River 551					
Chapter 13.	Design Criteria and Basis of Cost Estimates 552					
Chapter 14.	Sewerage and Drainage Subareas					
Part V. Sewerage and Drainage Plans						
Chapter 15.	Development of Sewerage Plans 553					
Chapter 16.	Stage Construction of Sewerage Facilities 554					
Chapter 17.	Development of Storm Drainage Plans 555					
Chapter 18.	Separation of Combined Sewers in the City of Seattle $556$					
Chapter 19.	Financing of Recommended Facilities 556					
CHAPTER 21.	RECOMMENDATIONS 558					
APPENDIX A.	ACKNOWLEDGEMENTS					
	Moment covered accounts					
APPENDIX B.	TOTAL COUNT METHOD B-1					
	DEPORT ON THE PROLOGY OF THE PORTON SURVEYOR					
	REPORT ON THE BIOLOGY OF THE BOTTOM SHELF OF					
PUGET SOU	UND, WEST POINT, SEATTLE, WASHINGTON, JULY 1957 C-1					
APPENDIX D.	RESULTS OF CURRENT STUDIES IN PUGET SOUNDD-1					
	PRELIMINARY SEWER PLANS AND PROFILES					
STAGE I CO	ONSTRUCTION, CENTRAL SEWERAGE SYSTEME-1					
	b					
APPENDIX F.	REFERENCES AND PHOTO CREDITSF-1					